OPERATIONAL TESTING OF PLANTING MACHINES IN THE BOREAL FOREST OF ONTARIO

III. TIMBERLAND TREE PLANTER

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ABSTRACT

Three operational machine-planting trials involving two Timberland Tree Planters were carried out on clay, sandy loam and sand soil types to determine the effectiveness of the machines for use in typical boreal forest cutover conditions in Ontario. Both the Timberland Plow (CFS V-blade) and the C & H Plow were used in these trials. Site conditions such as stumps, slash, residuals, soil, slope and ground roughness were assessed to determine their effect on planting rate and quality. Repairs and modifications during the trials resulted in a steady improvement in availability and utilization. Costs of machine planting and of the alternative of site preparation with hand planting are included for comparison.

The two most critical factors in machine planting continue to be the ability of the prime mover to clear a debris-free path immediately in front of the planting unit, and the use of uniform planting stock of acceptable size.

The Timberland Planter was found to be safe and rugged, adaptable to a range of planting sites and capable of planting those sites at reasonable cost.

RÉSUMÉ

Trois essais de plantage mécanique avec deux planteuses Timberland ont été effectués sur des sols de type argileux, limoneux-sableux et sablonneux pour déterminer l'efficacité de ces machines dans les conditions typiques des forêts boréales exploitées dans l'Ontario. Les charrues Timberland (CFS à lame en V) et C & H ont été toutes deux employées dans ces essais. On a évalué les conditions de la station telles que la présence de souches, rémanents et résidus, l'état du sol, la pente et la rugosité du terrain afin de déterminer leur impact sur la rapidité et la qualité du plantage. Des réparations et modifications durant les essais ont apporté une amélioration constante de la disponibilité et de l'utilisation des machines. Les coûts du plantage mécanique et ceux de la préparation de la station qui autrement s'impose avec le plantage manuel sont inclus à des fins de comparaison.

Les deux facteurs les plus critiques du plantage mécanique sont toujours l'habileté du premier moteur à nettoyer une voie libre de débris immédiatement devant l'unité planteuse et l'emploi de plants uniformes d'une taille acceptable.

La planteuse Timberland s'est avérée sûre et robuste, adaptable à une variété de sites de plantation et capable de fonctionner sur ces stations à coût raisonnable.

ACKNOWLEDGMENTS

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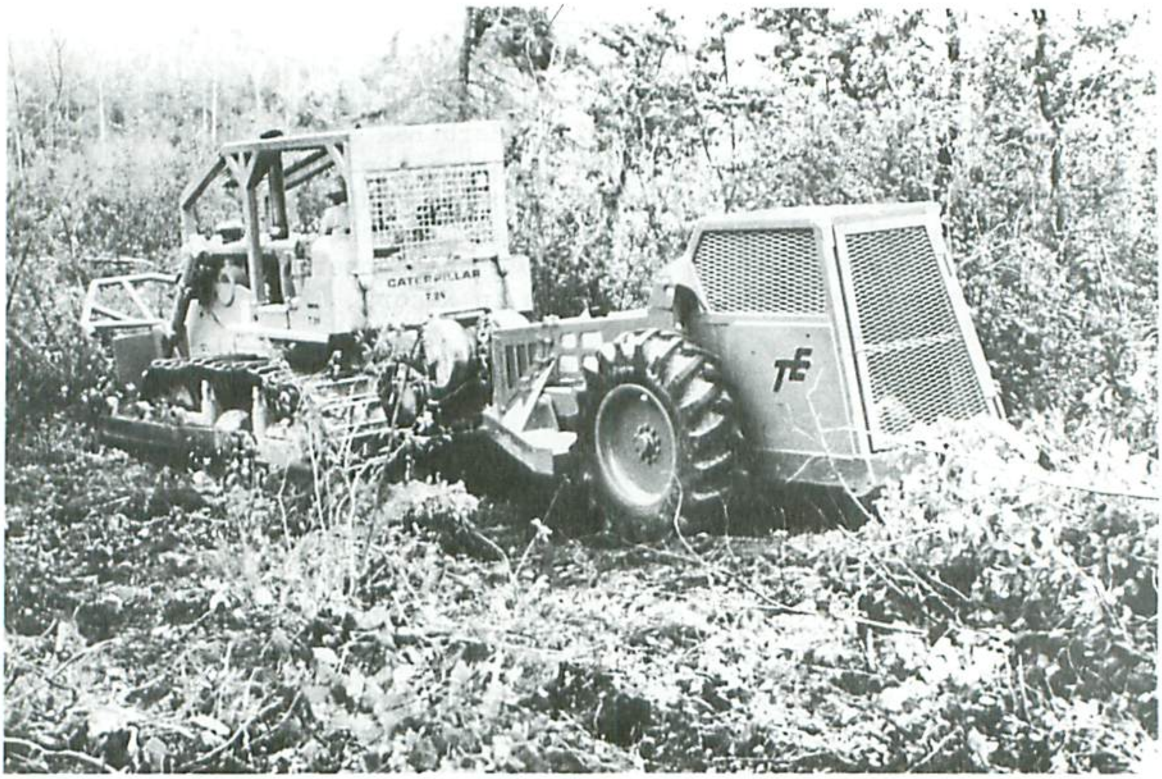

Frontispiece. The complete planting unit: Timberland Plow, Caterpillar D7E Bulldozer, and Timberland Planter.

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INTRODUCTION

The Timberland Planter represents the culmination of 10 years of research and development since the production of the first conceptual drawings of a "fully automatic (multi-row) nursery stock planting machine" was undertaken by the then Ontario Department of Lands and Forests in 1969. Construction of the initial machine, called the All Terrain Planter, took place in 1971. Later it was designated the Ontario Mark I Planter. The Mark II was constructed in 1972, and in 1974 a limited number of Ontario Mark III Planters were constructed on a commercial basis. Cooperative testing of, and modifications to, the Mark III by the Ontario Ministry of Natural Resources (OMNR) and the Great Lakes Forest Research Centre (GLFRC) led to an agreement late in 1977 with Timberland Equipment Ltd. of Woodstock, Ontario, to produce a patented, preproduction model, the "Timberland Planter". This unit underwent shakedown tests in 1978 and subsequently a commercial version was produced. OMNR then purchased two Timberland Planters and plows for operational use and for demonstration to OMNR personnel during the 1979 planting season.

KBM Forestry Consultants Inc. of Thunder Bay, Ont., under contract to OMNR, carried out operational planting with these machines on three sites across northern Ontario. OMNR provided the planting sites and the planting stock and KBM provided the bulldozers, maintenance equipment and personnel to maintain and operate the planters. In addition to KBM's records of the day-to-day operation, daily assessments of stock quality and planting quality were provided by F. R. Clarke[1] and R. J. Day[2], who were hired by OMNR. Canadian Forestry Service (CFS) personnel conducted detailed site assessments, work studies and planting quality assessments.

This was a major operational trial undertaken to determine the planter's ability to cope with various planting sites, to point out further areas for design modification, to improve planting quality and machine performance, to determine efficient operating techniques, and to demonstrate the feasibility of mechanized planting in Ontario's boreal forest conditions.

EQUIPMENT

A complete operational planting unit consisted of the planting machine, the prime mover, and a site clearing attachment (e.g., a V-blade) (See Frontispiece). Two complete units were in operation during the trials.

Planting Machine

The Timberland Planter is identical in function and operation to the Ontario Planter as described by Scott (1975). It rides on two

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large skidder tires and is attached to the bulldozer by means of a pin hitch. A large enclosed cab with heavy-duty suspension seat allows the planter operator to work in comfort and safety. All instruments and controls required for operation are contained within the planter cab. The planting beam, with depth sensor plate, the tree ejector and the packing wheels, are hydraulically operated. The operator loads bareroot seedlings manually into a pair of nylon fingers in a dibble on the planting beam and initiates the planting cycle by depressing a foot pedal. After the tree is planted, the ejector, packing wheels and planting beam return to their original position. The next tree can now be loaded.

Prime Mover

Caterpillar D7F powershift bulldozers with winches were used for the trials. The machines had track-frame guarding and R.O.P.S. canopies for bush use. The drawbars which are integral with the winch were of the rotating kind and had to be restrained from rolling to ensure planter stability on rough ground.

Site Preparation Equipment

Two types of V-blades were used during the trials, the Timberland Plow (Timberland Equipment Ltd. version of the CFS V-blade) described by Cameron (1978) with optional floating linkage and the C & H Plow (Fig. 1) described by Clarke (1977).

The Timberland Plow is equipped with a bunting frame for directing standing debris away from the bulldozer. A central V-nose, incorporating a rolling drum coulter, follows the ground contours while supporting the weight of the blade and tractor C-frame when the bulldozer's hydraulic control lever for the blade is in the float position. The V-nose continuously clears a 75 cm wide path of all debris while leaving the soil intact for the subsequent tree planting operations. Wings bolted 35-45 cm above ground level on either side of the central V-nose provide tractor protection and additional slash parting capability.

The C & H Plow incorporates a plow within a plow. The outer plow has a small rolling drum to support the 'rhinocerous horn' slash parter and the side arms. This provides tractor-width clearing of slash from the site. The inner plow has a pair of scalping wings forming a V which scrapes into the mineral soil in a 1.88 m wide swath. The tractor operator must work the blade to provide the required depth control.

PLANTING SITES

The Timberland Planters operated on three planting sites in northern Ontario over the 1979 planting season.

Vermilion Bay Site

In May and June a site (50°21'N, 93°43'W) in Kenora District about 60 km NNW of Vermilion Bay, Ont. near Boise-Canada Ltd. Camp 255 was planted. It has also been referred to as the Hector Creek site.

The site (Fig. 2) has resulted from post-glacial deposition of lacustrine material. It has a low overall relief occasionally broken by features such as morainic ridges, rock outcrops and fluvial terraces. The soil is a deep, relatively stone-free clay, with a duff depth of usually less than 7 cm. It was harvested two years previously for jack pine (*Pinus banksiana* Lamb.). Poplar residuals (*Populus tremuloides* Michx., *P. balsamifera* Moench) and white spruce (*Picea glauca* [Moench] Voss) were scattered over most of the area, the poplars numerous on some of the lower ground. This forest type is common in the Lower English River Section of the Boreal Forest Region (Rowe 1972).

Minor vegetation in the area was light. Slash over 7 cm in diameter averaged 73 m^3/ha.

Upsala Site

From mid-July to early August planting took place in Thunder Bay District (49°02'N, 90°43'W) about 160 km west of Thunder Bay near Great Lakes Forest Products Ltd. Camp 134 on the lower Firesteel Road. The Colliver Twp site (Fig. 3) lies in the Upper English River section of the Boreal Forest Region (Rowe 1972). The forest cover consisted mainly of a mixture of white spruce, balsam fir (*Abies balsamea* [L.] Mill.), trembling aspen (*Populus tremuloides* Michx.) and white birch (*Betula papyrifera* Marsh.). Red pine (*Pinus resinosa* Ait.) and white pine (*P. strobus* L.) reach their northern limits here and occurred as scattered individuals and isolated clumps.

The terrain is strongly glaciated and has a rough, rolling topography, with some plateau features. Deep-soiled lacustrine flats and till plains occur and podzol profiles, where developed on the finer-textured surface materials, provide excellent conditions for tree growth.

The soil is a sandy loam with few stones and boulders within 30 cm of the surface. The topography ranges between moderate slopes and flat expanses. The site was logged over a three-year period (1977-1979) with cut and skid crews and a Koehring Shortwood Harvester. Aspen and birch residuals predominated over the area. Minor vegetation in the area was assessed as medium to heavy and included poplar suckers averaging 85 cm in height. Duff was generally about 5 cm thick. Slash over 7 cm in diameter averaged 60 m^3/ha.

Foleyet Site

From mid-August to mid-September planting took place in Chapleau District, Oates Twp (48°25'N, 82°25'W) about 25 km north of Foleyet. This district lies at the northern boundary of the Missinaibi-Cabonga section of the Boreal Forest Region (Rowe 1972).

The predominant forest had been a mixture of balsam fir, black spruce (*Picea mariana* [Mill.] B.S.P.) and white birch with scattered white spruce and aspen. Jack pine dominated the sand terraces prior to logging. The topography is rolling, but with numerous flats along the rivers and lakeside.

The soil, a podzol, is a deep sand with deep organic accumulations in the depressions. The area (Fig. 4) had been logged previously and a prescribed burn conducted two weeks prior to the planting operation removed the bulk of fine slash, minor vegetation and duff from the site. Of slash greater than 7 cm in diameter, approximately 44 m^3/ha remained on site.

ASSESSMENTS

Prior to planting, the site was assessed for those physical factors that might affect the passage of the tractor or the planter, the mechanics of planting and packing, and subsequent survival[3].

Time studies were carried out to evaluate operational effectiveness and to pinpoint reasons for delay and inadequate performance. Post-treatment assessments of the planting were conducted to provide further feedback on the operation. The assessment included number of trees per hectare, planting depth, and packing quality, all of which are factors that affect stocking and survival and can be controlled during the planting operation.

Planting depth and packing are the most obvious and easily measured parameters of planting quality. Planting depth was described as deep, satisfactory, or shallow. The deep category was assigned to spruce when any part of the uppermost branch whorl was under soil and to jack pine when the base of the terminal bud was at or below soil level. The shallow category was assigned when roots were visible on the stem for all species. Any condition between shallow and deep was considered satisfactory. The planted seedlings were assessed as 'firm' if they did not yield to a 2.25 kg tug. If they budged, they were recorded as 'loose'. Both the 'deep' and 'satisfactory' trees were considered likely to survive and grow if some foliage and the terminal bud were above ground and the seedling was firmly planted (Sutton 1966).

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[3] Further information on assessment can be found in Riley (1975).

Figure 1. Vermilion Bay clay site. Timberland Plow, D7F Bulldozer, and Timberland Tree Planter weave through poplar residuals in southern corner of planting area.

Figure 2. The C & H Plow used with the Timberland Planter in Upsala.

Figure 3. Upsala site. Plot 3 looking southeast.

a) before planting b) after planting

Heavy brush is evident in Figure 3a), with some scattered residuals.

Figure 4. Foleyet site. Plot 1 looking northwest.

a) before planting b) after planting

A prescribed burn has removed most of the debris with the exception of the large boles on this sandy site.

The tree seedlings were also assessed for overall planting quality. The assessment in each case was based on the combined features of planting depth, firmness of packing and other circumstances such as injury, lean, and exposed roots.

The planting attempt was therefore assessed as 'satisfactory' if the tree was 'firm' and planted at 'satisfactory' depth. It was 'fair' if one of the above parameters was different. For example, a tree was called 'fair' if it was planted to a satisfactory depth and was slightly loose, or had some roots exposed, was leaning more than 45° from vertical (Fig. 5), or had sustained a minor injury during planting. It might also be called 'fair' if it was firmly planted and was 'deep' or 'shallow'. In round figures based on planting quality the 'fair' tree had a 50:50 chance of survival in the assessor's judgment. Shallow trees, missed planting attempts, dropped trees, and various other circumstances related to planting quality were called 'not planted'.

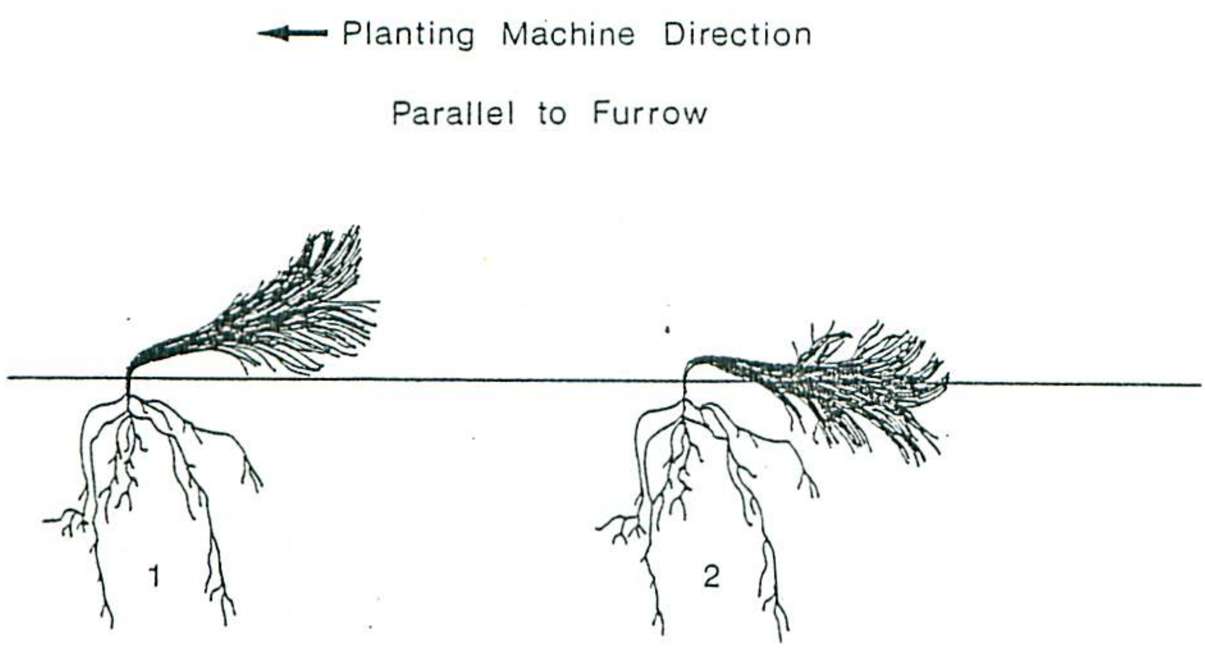


Figure 5. Schematic representation of tree seedling crown position resulting from planting limp stock. Tree no. 1 tallied as 'fair', no. 2 tallied 'not planted', the result of stock quality rather than machine performance.

RESULTS

Pretreatment

Tables 1 to 6 summarize the pretreatment assessment data.

Stumps were fewest at Upsala and most frequent at Foleyet (Table 1). Slash greater than 7 cm in diameter ranged in volume from almost 10 to 145 m^3/ha, averaging about 60 m^3/ha (Table 2). Foleyet had the least slash because a prescribed burn had been conducted to reduce slash volumes on the site before planting. Brush (Table 3) was very heavy at Upsala and almost nonexistent on the other sites. In terms of slope (Table 4), Vermilion Bay was the most moderate with over 60% of the area being level. Foleyet and Upsala were both rolling sites with 31% to 35% level area.

Minor vegetation was characterized as medium to heavy at Upsala with almost 70% coverage (Table 5), but it was nil to light on the other sites. Ground condition gives an indication of soil trafficability and is described on the basis of soil type, ground moisture and stone or boulder content (Anon. 1969). On a scale of 1 to 5 where 1 is the easiest and 5 the most difficult, the class 4 in Vermilion Bay (Table 5) is between an average and a very poor site, i.e., clay on a fresh to moist site, in terms of trafficability. Foleyet and Upsala with class 2, i.e., sandy to loamy moraine on dry to fresh sites, are between very good and average trafficability.

Bedrock, stones and boulders covered approximately 10% (Table 6) of the area within the first 30 cm of soil depth in Vermilion Bay. Upsala had about 2%. Ground roughness (Anon. 1969) was a class 2 for all three sites. On a scale of 1 to 5 where 1 is a very even ground surface and 5 is a very rough ground surface, class 2 described a site between a very even and a somewhat uneven surface.

Time Studies

Table 7 provides a summary of all times recorded in the time studies for the trials. The times are broken down by category (e.g., 'stop planter') and reason (e.g., 'supplying stock'). 'Forward' is considered productive time, during which planting is carried out. The other categories represent nonproductive time. The 'stop' and 'reverse' categories allocate delay time to either the tractor or the planter and designate the specific cause of delay. 'Manoeuvring' identifies those periods when the unit was travelling but not actually planting trees. 'Personal' time included work stoppages for coffee breaks, extended lunches, etc. Appendix I gives definitions and groupings.

Table 1. Stump assessment.

Location	Frequency (No./ha)	Avg ht (cm)	Ht range (cm)	Avg diam. (cm)	Diam. range (cm)
Vermilion Bay	788	26.1	8 - 140	23.0	4 - 44
Upsala	391	34.1	6 - 120	29.4	6 - 52
Foleyet	1138	21.8	6 - 49	20.4	6 - 56
Over all[a]	731	27.4	6 - 140	23.4	4 - 56

[a] Weighted averages where appropriate.

Table 2. Slash assessment.

Location	Pieces per 20 m of lineal tally < 7 cm	Pieces per 20 m of lineal tally 7 cm+	Avg diam. (cm)	Diam. range (cm)	Volume 7 cm+ m^3/ha	Volume range m^3/ha
Vermilion Bay	30.5	7.3	12.7	8 - 26	73.2	29.2 - 139.7
Upsala	32.3	6.2	12.7	8 - 32	60.5	12.8 - 112.7
Foleyet	17.5	9.8	12.1	8 - 42	44.0	9.9 - 145.8
Over all[a]	27.6	7.6	12.6	8 - 42	60.2	9.9 - 145.8

[a] Weighted averages where appropriate.

Table 3. Residual assessment.

Location	Brush		Frequency		Avg DBH (cm)	Diam. range (cm)	Avg ht (m)	Ht range (m)
	Density (No./ha)	Stocking[a] (%)	< 10 cm DBH (No./ha)	10 cm+ DBH (No./ha)				
Vermilion Bay	396	4	17	103	24.5	4 - 42	NA	NA
Upsala	13,982	80	44	66	17.8	4 - 50	10.4	2 - 28
Foleyet	250	3	10	50	21.4	4 - 44	14.8	3 - 30
Over all[b]	5,639	33	26	74	21.3	4 - 50	11.5	2 - 30

[a] Stocking based on 4 m^2 quadrats.

[b] Weighted averages where appropriate.

Table 4. Slope assessment.

Location	Level (± 2% slope) (% of lineal tally)	Avg upslope (%)	Max. upslope (%)	Length of max. upslope (m)	Avg downslope (%)	Max. downslope (%)	Length of max. downslope (m)
Vermilion Bay	63	6.0	6	13	- 4.2	- 18	20
Upsala	31	7.2	18	20	- 4.8	- 8	20
Foleyet	35	6.4	24	8	- 7.5	- 24	6
Over all[b]	43	6.8	24	8	- 5.5	- 24	6

[a] Stocking based on 4 m^2 quadrats.

[b] Weighted averages where appropriate.

Table 5. Soil and vegetation assessment.

Location	Minor vegetation type	Visual assess.	% cover	Ht (cm)	Depth to min. soil (cm)	Soil texture	Soil depth (cm)	Soil moisture (cm)[a]	Ground condition[b]
Vermilion Bay	hazel, club mosses, grasses	light	16	19	6	clay	> 60	40% dry-fresh 15% fresh 45% fresh-moist	4
Upsala	Poplar suckers, alder, hazel, moose maple, willow, raspberry, viola and grasses	med-heavy	69	85	5	sandy loam	> 60	dry-fresh	2
Foleyet	(70% burnt, nil veg.) Poplar suckers, vaccinium, grass	nil-light	14	34	5	sand to fine sand	> 50	dry-fresh	2

[a] Using Hills' (1955) classification.

[b] Assessed according to Swedish terrain classification system (Anon. 1969).

Table 6. Stoniness and ground roughness assessment.

Location	Stoniness		Boulders		Bedrock		Ground roughness[c]
	areal coverage[a] (%)	stocking[b] (%)	areal coverage[a] (%)	stocking[b] (%)	areal coverage[a] (%)	stocking[b] (%)	
Vermilion Bay	3	13	5	5	3	15	2
Upsala	1	11	1	11	nil		2
Foleyet	nil		nil		nil		2

[a] A steel rod was shoved into the soil every 2 m along a sample line in each subplot. If a stone or boulder was encountered within the first 30 cm of mineral soil, it was recorded and a % occurrence figure was provided for each subplot. This % occurrence was averaged for all subplots to give the areal coverage figure, i.e., stones occupied 3% of the area in Vermilion Bay down to a 30 cm depth of mineral soil.

[b] A binary yes/no assessment of stones, boulders and bedrock by subplot gives the stocking, i.e., 13% of the subplots in Vermilion Bay contained stones.

[c] Assessed according to Swedish terrain classification system (Anon. 1969).

Table 7. Work study time summary for Timberland Planter trials in terms of basic motions and functions on three sites of varying difficulty.

			Vermilion Bay minutes	%	Upsala minutes	%	Folevet minutes	%
Forward			1 485.35	24.9	1 941.11	51.7	1 205.91	52.0
Stop planter								
clearing debris	WO		69.17		221.94		46.16	
breakdown	IR							
limit switch & bracket			77.57					
trigger plate			219.07					
planting beam cylinder			114.34					
crack in planting beam			142.30					
planting beam guide			77.26					
ejector pad			7.58					
ejector			615.22					
ejector fittings					145.36			
ejector plate							45.87	
hydraulic hoses			119.69					
waiting for hoses			1 440.00					
hydraulic leaks			68.40		252.29			
overheating			77.59					
oil cooler					46.82			
starting problems (shut off valve)					36.20			
air lock					41.10			
pressure relief valve					49.02			
check valve					41.00			
fingers			35.03		19.62			
hitch pin			11.02		37.94		36.78	
hitch (tractor)					40.62			
door			3.19					
winch cable					10.59			
refueling	IS				35.77			
servicing	IS		153.48		123.52		26.43	
engine warmup	OL		2.26					
supplying stock	OL		165.28		85.21		46.05	
changing operators	OL		70.16		90.59		52.49	
instruction - Timberland		WO	.40		3.58		9.07	
- CFS		NA	20.73		3.53		2.28	
- KBM		WO	6.53				1.37	
other	WO		20.75		4.49			
wait for hand planters		OL			35.00		43.71	
Total			3 517.02	59.1	1 324.19	35.3	310.21	13.4

(continued)

Table 7. Work study time summary for Timberland Planter trials in terms of basic motions and functions on three sites of varying difficulty. (concluded)

			Vermilion Bay minutes	%	Upsala minutes	%	Folevet minutes	%
Stop tractor								
clearing debris	WO		2.93		12.98		.12	
breakdown	PM				5.09		220.00	
servicing	PM		18.30		1.52		3.00	
starting	PM		9.12					
refueling	PM		12.34					
servicing - V blade		PM	1.13				3.00	
instruction - Timberland		WO	.85					
- CFS		NA	2.47		.85		3.08	
- KBM		WO	13.68		3.75			
other	OL		2.68					
stuck	OL		34.50		58.45		141.18	
rest	PM		20.56		18.41		28.15	
not available	PM				120.01		156.46	
Total			118.56	2.0	221.06	5.9	554.99	23.9
Reverse tractor								
clearing debris	WO		.91	-	2.37	0.1		
Reverse planter								
clearing debris	WO		1.13					
Manoeuvring								
clearing debris	WO		22.67		43.46		12.89	
turn	WO		233.58		120.49		111.92	
changing sites	IM		16.47					
walking in, out	IM		105.78		63.66		84.65	
other	OL		.47		5.25		2.84	
stuck	OL				2.85		7.86	
instruction CFS	NA				4.47			
Total			378.97	6.4	240.18	6.4	220.16	9.5
Personal								
rest	Pe		62.26		26.58		26.44	
other (weather, ½ day off),		OL	390.00					
Total			452.26	7.6	26.58	0.7	26.44	1.1
Grand Total			5 954.20	100.0	3 755.49	100.0	2 317.71	100.0

WO = work oriented time
IS = inshift service time
IR = inshift repair time
IM = inshift moving time

OL = operational lost time
Pe = personal time
PM = prime mover time
NA = non-available time (See Appendix I)

The important features to note in Table 7 are the 'stop planter' and 'manoeuvring' categories. The former category contains delays normal to any machine planting operation. The times indicated are high in Vermilion Bay and Upsala mainly because of the large number of mechanical breakdowns experienced with the planter. The Foleyet job was almost free of breakdown, and this shows favorably in the time study results. With the exception of the time spent 'waiting for hand planters' and 'refuelling' in Upsala, operating practice was good. Over the three trials, 'stop planter' time averaged 45.1% of available time, but it was only 16.2% in the Foleyet trial.

'Clearing debris' refers to the removal of material that would interfere with the forward progress or operation of either the tractor or the planter. In a change from previously reported trials, to comply more closely with standard definitions (Bérard et al. n.d.) used in the logging industry, time items directly related to the process of continuing to move forward while planting, such as 'clearing debris', instructions and directions to the planter operators, 'turning' at the end of a planting row in order to begin planting again on the next row and 'other', are work-oriented categories and are included in the 'productive' figures. Overall productive time was 49.3%, and a steady improvement can be seen from Vermilion Bay (31.7%) to Upsala (65.5%) to Foleyet at 73.1%.

The remaining features under the 'stop planter' category are mainly delay elements listed under 'breakdown'.

We found that a number of hydraulic or mechanical components gave trouble over the trials. Initially, in Vermilion Bay, undersize or understrength components such as limit switches and brackets, trigger plate (sensor plate) attachment, planting beam cylinder and ejector, as well as the need to wait for special order hydraulic hoses, made up the bulk of this downtime. Some of these faults were the result of economies in producing a production model, but all were corrected and offered no further trouble. By the time of the Upsala trial, with the exception of some leaking hydraulic fittings, the main hydraulic downtime resulted from unexplained overheating and the time spent removing and replacing various components in an attempt to determine the cause. Overheating, which continued for the duration of the trials, resulted in longer cycle times but no stoppages. After a complete overhaul of the machines and a thorough inspection of components over the winter the cause of overheating was determined and the problem was alleviated.

One delay mentioned earlier deserves explanation. This is the 'wait for hand planters' which occurred because of the planting system employed. Two operators were assigned to each planting machine, the one relieving the other in the planter. The one not in the machine followed and corrected misplants and planted additional trees where spacing required it. At lunchtime, the machine operation was suspended, but the tractor was still being paid for until the hand planter caught up, and then lunch was begun. Although this did not occur very often, a change in scheduling would eliminate the problem.

When machine planting is carried out in a parallel row system, turning at the end of the row becomes a necessary part of the operation; the longer the rows the less turning is involved on a proportional basis. From a supervisory point of view, parallel rows are the tidiest, allowing hand planters to keep track of their lines and always providing complete coverage within the working area. Should breakdowns occur, previously planted rows are not destroyed when a disabled machine is being walked out as could be the case with an outline or a lands pattern of planting.

Some 'nonproductive' elements in no way reflect on the efficiency of the planting machine, e.g., tractor problems and research-related delays are not included in the available time calculated for the planting machine. Instructions to the tractor operator or planter by research staff would not occur during a normal operation.

The 'stop tractor' category contains two time elements of note: 'stuck' and 'not available'. Because two machines were operating in close proximity, when one got stuck, the other would be sent to assist, thereby becoming 'not available'. This results in delays which affect costs of the overall operation, but does not affect planting machine availability. 'Stuck' times can never be entirely avoided, but can be reduced considerably with close supervision and instruction, and some basic tools for "self help". An axe and a chainsaw can often be used to free a bulldozer before the problem becomes too serious. Certainly, experienced and motivated bulldozer operators are an asset in keeping this downtime to a minimum.

Overall planting machine availability, designated as operating time in Table 8, was 63.5%. This is below the industrially accepted 80% availability. However, the Upsala trial maintained 75.6% availability and the Foleyet trial reached 94.3%. With the removal of some non-recurring 'breakdown' elements in the 'stop planter' category, the overall operating time should exceed the 80% level. If only the time spent waiting for hydraulic hoses, the ejector repair, limit switch removal and trigger plate beefing up had been removed, the overall operating time on these trials would have been 80.1%.

Tables 8 and 9 make use of the terms 'available' and 'availability', and it is important that the meaning be understood. We are basically interested in the performance of the planting machine itself, and although we want to ensure that the bulldozer and the V-blade are being used efficiently and are in satisfactory mechanical condition to perform throughout the scheduled operating period, it is

Table 8. Time breakdown in terms of productive and non-productive effort.

	Vermilion Bay		Upsala		Foleyet			
	minutes	%	minutes	%	minutes	%	minutes	%
Productive (1)	1 857.95	31.7	2 359.42	65.5	1 390.28	73.1	5 607.65	49.3
Nonproductive								
Nonmechanical delay (2)	849.86	14.5	362.34	10.1	402.38	21.2	1 614.58	14.2
Mechanical delay (3)	3 161.74	53.9	879.85	24.4	109.08	5.7	4 150.67	36.5
Nonavailable (plow) (4)	1.13	-	-		3.00	.2	4.13	-
Nonavailable (tractor) (4)	60.32	1.0	145.03	4.0	407.61	21.4	612.96	5.4
Nonavailable (CFS) (4)	23.20	.4	8.85	.2	5.36	.3	37.41	.3
Scheduled operating time Total time (1 + 2 + 3 + 4)	5 954.20	101.4	3 755.49	104.3	2 317.71	121.9	12 027.40	105.8
Tractor and V-blade Available time (1 + 2 + 3)	5 869.55	100.0	3 601.61	100.0	1 901.74	100.0	11 372.90	100.0
Planter Operating time (1 +2)	2 707.81	46.1	2 721.76	75.6	1 792.66	94.3	7 222.23	63.5

Productive = prod. + WO
NM.D = OL + Pe + IM
M.D. = IR + IS.

expected that a small proportion of time will be devoted to these two items. However, for the purpose of these trials, delays due to the tractor or V-blade were removed to provide an available time which equalled 100%. This is the basis on which the planter was assessed and planter operating time was synonymous with planter available time.

Table 9. Planting machine availability and utilization summary.

	Vermilion Bay	Upsala	Foleyet	Over all
Availability (%)	46.1	75.6	94.3	63.5
Utilization (%)	31.7	65.5	73.1	49.3

From Table 9, overall availability of the planting machine was 63.5% and utilization[4] was 49.3%. This matches closely the contractor's own records for the total operation, which show 65% availability and 47% utilization (Anon. 1979). Marked improvement in utilization can be seen as the season progressed (i.e., from 31.7% in Vermilion Bay to 73.1% in Foleyet). Availability likewise improved as planting progressed.

Planting Quantity

Interrow spacing is controlled by the tractor operator and the V-blade so that a planting prescription which indicates a desired number of trees per unit area can be attained (once the interrow spacing is established) only by varying the number of trees planted along the row. Interrow spacing of 2.4 m was considered a reasonable and attainable goal for machine planting in boreal forest cutover conditions (Cameron 1975).

In three separate trials, three different tractor operators were assessed and on two of the three sites the Timberland Plow was assessed while the C & H Plow was assessed on the Upsala site. All tractor operators had a breaking in period with the planting machines before they entered the research plots. Although they had similar experience with the planting machines the operators differed in ability.

The number of trees planted per unit area is related to the effectiveness of the V-blade (which must prepare the site), tractor speed and the planter operator's manual dexterity (Fig. 6). Table 10 shows interrow spacing in Upsala at 2.82 m while spacing at Vermilion Bay and Foleyet was 2.44 m and 2.47 m, respectively. The number of

[4] Definitions of availability and utilization as well as a schematic of machine time elements are contained in Appendix I.

trees per ha varied accordingly: 1395/ha in Upsala, 1897/ha in Vermilion Bay, 1889/ha in Foleyet.

Figure 6

A rear view of the Timberland Planter showing the planted row. This photograph was taken at the shakedown trial in early spring, 1979, in southern Ontario.

Over all, 40.1 ha were sampled and 67,383 trees were machine planted on this area, for an average of 1680/ha. Of 200.5 scheduled operating hours (of which the tractor and plow were available for 189.5 hr), 93.5 hr were devoted to planting for a planting rate of 721 trees/productive hour. A marked improvement is shown in trees planted per productive hour between Vermilion Bay (740/hr) and Foleyet (887/hr), but the rate at the Upsala trial was considerably lower because of overheating problems which slowed the planting cycle. Tractor speed has a direct bearing on intertree spacing and therefore on trees per unit area. The physical limitations of both planting machine and operator dictate the maximum number of trees that can be planted during a given time. Slower forward speeds result in a smoother ride for the planter operator and closer intertree spacing. The increased comfort favorably influences intertree spacing. Tractor speed averaged 2.0 km/hr and ranged from 1.7 to 2.4 km/hr.

Planting Quality

Planting depth and packing are the most obvious and easily measured parameters.

In terms of the overall job, 45.7% were planted "satisfactorily', 21.5% were 'fair', and 32.8% were 'not planted' out of 5037 planting attempts assessed (Table 11).

The major reasons for allocation to the 'fair' or 'not planted' categories were loose planting 8.9%, shallow planting and/or exposed roots 8.4%, no site preparation 7.9%, and deep planting 6.6%. Leaning, buried or injured trees, soft soil, deep furrows and poor slit closure accounted for the remainder of the 54.3% in the 'fair' or 'not planted' categories.

Of other parameters assessed in determining planting quality, we found that close interrow spacing resulted in some debris being sloughed off onto adjacent planted rows in areas where there were high concentrations of debris. The Upsala site was the only one on which brush densities caused a debris problem. The use of the C & H Plow in this condition increased the width of the cleared swath for planting, but in doing so, also increased the amount of material to be windrowed. The result was wider interrow spacing with a somewhat greater percentage of trees (11.8%) being adversely affected by the subsequent planting of adjacent rows. Over all, 9.8% were affected.

At Vermilion Bay, Timberland Plows were used with both planters. At Upsala and Foleyet a Timberland Plow was used with one machine and the C & H Plow with the other. Our assessments dealt with one planting machine per site. The Timberland Plow used on both the Vermilion Bay and the Foleyet sites resulted in substantially more planting attempts/ha than the C & H Plow used at Upsala. However, Upsala was noted as being a considerably more difficult site to plant because of the abundance of brush. The OMNR contract study by Day and Clarke, conducted at the same time as these trials, assessed planting quality with both machines after hand correction and fill-in. A distillation of its findings is incorporated into this report. In Table 12 the results for Upsala where the Timberland Plow was used with the second planting machine show that an average of 1128 machine planting attempts were made per ha (max. 1637 in 19-day observation period) with 67.6% giving satisfactory planting, while the C & H Plow averaged 1020 machine planting attempts (max. 1243 in 12-day observation period) with 64.9% noted as satisfactory. Over all, the Timberland Plow areas allowed 1832 attempts per ha for 78.4% success while the C & H Plow areas allowed 1646 attempts and achieved a 74.5% success. At the Foleyet site the spread increased in favor of the Timberland Plow.

Table 10. Planting production summary.

	Vermilion Bay	Upsala	Foleyet
Soil type	clay	sandy loam	sand
Total trees planted	22 948	23 486	20 589
Area planted-net (ha)	12.1	17.1	10.9
Trees planted/net ha	1 897	1 395	1 889
Duration of trial total elapsed time (hr)	99.6	62.6	38.6
Available time (hr)	97.8	60.0	31.7
(%)	100.0	100.0	100.0
Operating time (hr)	45.1	45.4	29.9
(%)	46.1	75.6	94.3
Productive time (hr)	31.0	39.3	23.2
(%)	31.7	65.5	73.1
Trees planted/available hr	235	397	649
Trees planted/operating hr	509	525	689
Trees planted/productive hr	740	607	887
Net area planted/available hr (ha)	.12	.29	.34
Net area planted/operating hr (ha)	.27	.38	.36
Net area planted/productive hr (ha)	.39	.44	.47
Avg forward speed (km/hr)	2.1	1.8	2.1
range (km/hr)	1.8-2.4	1.7-1.9	1.9-2.4
Avg intertree spacing (m)	2.16	2.54	2.10
Avg interrow spacing (m)	2.44	2.82	2.47
Avg spacing (m)	2.30	2.68	2.28

Table 11. Planting quality in terms of the number and percentage of trees affected.

Quality class	Vermilion Bay No. of trees	Vermilion Bay % of total	Upsala No. of trees	Upsala % of total	Foleyet No. of trees	Foleyet % of total
Satisfactory	617	50.8	919	45.0	764	43.0
Fair	172	14.1	502	24.5	410	23.0
Not planted	426	35.1	623	30.5	604	34.0
Total	1215	100.0	2044	100.0	1778	100.0
Depth						
deep	38	3.1	187	9.1	107	6.0
shallow	60	4.9	219	10.7	66	3.7
Packing						
loose	81	6.7	228	11.2	137	7.7
Other						
no site preparation	120	9.9	148	7.2	128	7.2
soft soil	79	6.5	30	1.5	42	2.4
leaning	8	.7	67	3.3	147	8.3
injury during planting	4	.3	5	.2	22	1.2
trees covered by debris during planting[a]	20	1.6	19	.9	162	9.1
trees with exposed roots	45	3.7	30	1.5	8	.4
other	143	11.8	192	9.4	195	11.0
Total (fair and not planted)	598	49.2	1125	55.0	1014	57.0
trees trampled, gouged out, buried by soil or debris from planting adjacent row[b]	121	10.0	242	11.8	131	7.4

[a] Trees were tallied immediately upon being planted and their condition was recorded (i.e., debris-covered or not).

[b] After passage of the tractor in the adjacent row, the above trees were again tallied and any additional debris was recorded from the planting of the adjacent row.

Table 12. Assessment of overall job[a]: planted results by site and plow.

	Machine attempts per ha	% successful	Hand corrected per ha	% successful	Additional hand attempts per ha	% successful	Total attempts per ha	% successful	Successful attempts per ha
TE Plow									
Upsala	1128	67.6	101	100.0	704	81.5	1832	78.4	1437
Foleyet	1827	69.5	208	100.0	466	89.9	2293	82.7	1896
C & H Plow									
Upsala	1020	64.9	102	100.0	627	73.8	1646	74.5	1227
Foleyet	1457	75.3	164	100.0	408	80.1	2147	74.0	1588

[a] Assessment carried out under separate OMNR contract. Results courtesy of F. R. Clarke, Associate Professor, School of Forestry, Lakehead University, Thunder Bay, Ontario.

These results indicate that the Timberland Plow, when used in conditions similar to those in which the C & H Plow was used, was superior for a single-row trailed mechanical planter in terms of number of attempts per ha, number successful per ha and overall number planted per ha after hand correction and fill-in.

The differences between the study results reported in Tables 12 and 13 in terms of attempts per ha are explained by the fact that 'before' and 'after' assessments were made on the machine planting attempts to determine the effect of planting the adjacent row. For the planting quality part of the contract only the final results were assessed, i.e., after burial of some trees by planting the adjacent row. In addition, although the studies were conducted on the same machines operating in the same area, they represent different amounts of coverage and different time periods.

Table 13 pinpoints the reasons for missed planting spots along the planting rows. Over all, 15.0% of each row was not planted. Stumps, even though fewest at Upsala (391/ha vs 788/ha at Vermilion Bay and 1138/ha at Foleyet), were the cause of almost twice (5.0%) as many of the missed planting spots as in either Vermilion Bay or Foleyet. Although this was due in part to the fact that the stumps were larger, the main reason was that using the wider C & H Plow increased the odds for stump contact. 'Other' causes of lost planting distance at Upsala include boulders encountered, the slower cycle speed as a result of overheating, tractor jerkiness (on encountering boulders or stumps), fumbling for trees, deep furrows, adverse grades and tractor manoeuvring, etc., with the C & H Plow. Despite an overall reduction in forward speed to 1.8 km/hr, intertree spacing was still considerably increased. The loss of 21.0% of the plantable row to stumps, debris and other causes, twice that of either Vermilion Bay or Foleyet, contributed to further decreases in the number of planting attempts/ha.

Table 14 gives a breakdown of planting quality by type of site preparation. Site preparation was termed satisfactory when the prescription to remove only the debris while leaving the mineral soil undisturbed was met. If the site preparation exposed mineral soil to a depth of 15 cm or more below the general surface level, it was designated 'deep furrow'. Mineral soil exposed, but above a depth of 15 cm, was designated 'shallow furrow'. The no site preparation category, 'none', included poor site preparation.

Of the sites that the machine attempted to plant, 17.7% had no site preparation and 6.4% had deep site preparation. Site preparation on the majority of sites was either 'satisfactory' or 'shallow furrow' (35.1% and 40.8%, respectively). The differences in numbers of individually prepared microsites for planting attempts between the C & H Plow at Upsala and the Timberland Plow at Vermilion Bay and Foleyet are rather indistinct. The Timberland Plow produced more of the 'satisfactory' and 'shallow furrow' conditions than did the

Table 13. Failure of machine to plant (by cause) in terms of fail length along the planting row.

	Vermilion Bay		Upsala		Foleyet	
	fail length/plot (m/m)	% fail	fail/length/plot (m/m)	% fail	fail length/plot (m/m)	% fail
Stumps	73/2660	2.8	238/5200	5.0	79/3760	2.1
Debris	98/2660	3.7	209/5200	4.4	189/3760	5.0
Other causes	174/2660	6.5	557/5200	11.6	129/3760	3.4
Total fail length	345/2660	13.0	1004/5200	21.0	397/3760	10.5

Table 14. Site preparation related to planting quality.

Site preparation	Satisfactory planting		Fair planting		Not planted		Total	
	#	%	#	%	#	%	#	%
None - Vermilion Bay	47	7.6	35	20.3	178	41.8	260	21.4
Upsala	52	5.6	62	12.3	245	39.3	359	17.5
Foleyet	54	7.1	57	13.9	161	26.7	272	15.3
Overall	153	6.6	154	14.2	584	35.3	891	17.7
Satisfactory - Vermilion Bay	306	49.6	79	45.9	114	26.8	499	41.1
Upsala	336	36.6	179	35.7	143	23.0	658	32.2
Foleyet	291	38.1	136	33.2	183	30.3	610	34.3
Overall	933	40.6	394	36.3	440	26.6	1767	35.1
Shallow Furrow - Vermilion Bay	253	41.0	54	31.4	119	27.9	426	35.1
Upsala	455	49.5	209	41.6	184	29.5	848	41.5
Foleyet	372	48.7	194	47.3	217	35.9	783	44.0
Overall	1080	47.0	457	42.2	520	31.5	2057	40.8
Deep Furrow - Vermilion Bay	11	1.8	4	2.3	15	3.5	30	2.5
Upsala	76	8.3	52	10.4	51	8.2	179	8.8
Foleyet	47	6.1	23	5.6	43	7.1	113	6.4
Overall	134	5.8	79	7.3	109	6.6	322	6.4
Total - Vermilion Bay	617	50.8	172	14.1	426	35.1	1215	100.0
Upsala	919	45.0	502	24.5	623	30.5	2044	100.0
Foleyet	764	43.0	410	23.0	604	34.0	1778	100.0
Overall	2300	45.7	1084	21.5	1653	32.8	5037	100.0

C & H Plow. The C & H Plow produced more 'deep furrow' than did the Timberland Plow.

It is obvious from Table 15 that a) the majority of the 'satisfactory' and 'fair' trees were planted on microsites that were rated as either 'satisfactory' or 'shallow furrow' in terms of site preparation and b) the 'not planted' category occurred most frequently on microsites which were not site prepared.

Table 15. Site preparation related to planting quality.

	Planting quality			
Site preparation[a]	Satisfactory (%)	Fair (%)	Not planted (%)	Total (%)
None	11.8	25.3	62.9	100.0
Satisfactory	39.2	35.1	25.7	100.0
Shallow furrow	38.9	35.0	26.1	100.0
Deep furrow	29.4	37.1	33.5	100.0
Average	29.8	33.1	37.1	100.0

[a] The site preparation conditions were weighted to produce equal amounts of the four different conditions, i.e., 100 each of none, satisfactory, shallow furrow and deep furrow. On the overall job (shown in Table 14), of every 400 conditions, 71 would be none, 140 would be satisfactory, 163 would be shallow furrow and 26 would be deep furrow.

In the Lakehead University School of Forestry study referred to earlier we have an additional site comparison between the two plows on the same sites (Table 16). The exposure of more mineral soil with the wider C & H Plow is to be expected. However, the number of planting attempts was actually less than with the Timberland Plow (1646 vs 1832 at Upsala and 2147 vs 2293 at Foleyet). Although more mineral soil may be exposed by the C & H Plow, the planting machine is a single-row planter and clearing to either side of the outside operating width of the planter's components, besides increasing interrow spacing, is unnecessary.

Costs

Although these were assessments of an operational planting job rather than a research trial, the costs were higher than expected. The calculated costs (Table 17) are based on total costs for the operation

Table 16. Comparison of plows.[a]

	Site conditions	Site preparation: Min. soil exposure gross[b] (%)	Duff exposure gross[b] (%)	Plantable area (%)	Planting attempts[c] per ha
Upsala job					
Timberland Plow	similar	14.5	3.5	41	1832
C & H Plow		14.2	3.2	38	1646
Foleyet job					
Timberland Plow	Similar but Timberland Plow worked in twice as many stumps as C & H	14.9	1.4	58	2293
C & H Plow		21.6	0.8	73	2147

[a] Results courtesy of F. R. Clarke, Associate Professor, School of Forestry, Lakehead University from assessments conducted under OMNR contract.

[b] % coverage on a unit area basis, e.g., 14.5% of the area was exposed to mineral soil.

[c] Represents both machine and hand planting attempts.

as submitted by the contractor. They include standby time for the bulldozers while modifications were made, and planting crew wages for such nonproductive effort, float costs to move the machinery from site to site acress northern Ontario and wages and room and board during these moves, planting small chances 1-2 ha in size on one site, vehicle rental, miscellaneous costs, overhead and contractor's profit.

In addition to costs at the individual sites, the costs of that portion of the job encompassed by the detailed time study and assessment outlined in this report have been calculated on the basis of availability, utilization, area treated and number of trees planted. (Note that for 80% stocking, 2000 trees/ha, cost/ha will be twice the cost/M).

It should be noted that, over all, the average number of trees/ha was 1855 and that the average number of trees/ha in the time study plots where no handplanting was allowed was 1692.

The revised costs of Table 17 reflect the removal of certain nonrecurring modifications and repairs to the planter. These problems have been overcome with the modifications and there should be no further difficulties in terms of downtime.

The costs are based on 260 ha planted for the job as a whole of which 40 ha were subjected to time study. A number of stoppages listed under the 'stop planter' category in Table 7 which would not occur in any further planting operations were removed for purposes of calculating revised costs on the 40 ha trial. The savings in wages and tractor rental from a 39.2 hr reduction in a 189.6 hr trial result in the revised costs listed. All costs have been rounded to the nearest dollar.

The costs for a projected normal operation are 60% higher than those for the alternative of site preparation and hand planting on a per unit area basis and on a cost per thousand basis. The reasons for these higher costs are given in the next section.

Table 17. Costs for machine planting (1979 dollars).

	District avg[a]		Calc. cost[c]		Revised cost[d]	
	per ha	per M[b]	per ha	per M	per ha	per M
Vermilion Bay	353	228				
(trial)[e]			1161	612	786	414
(job)			752	651	-	-
Upsala	355	190				
(trial)			577	414	488	350
(job)			929	572	-	-
Foleyet	279	133				
(trial)			492	261	482	256
(job)			687	539	-	-
Over all	329	181				
(trial)			703	418	551	328
(job)			767	577	-	-

[a] Cost established by the district for site preparation and hand planting based on experience from previous years.

[b] 2000 trees/ha used in calculating cost per thousand, Upsala 1866/ha, Foleyet 2088/ha.

[c] Calculated costs are based on number of ha planted, machine productivity and utilization.

[d] Revised cost reflects subtraction of 39.2 hr which entailed wait for hydraulic hoses, ejector repair, limit switch and trigger plate.

[e] Cost for the complete job on each site and the overall cost were supplied by KBM. Costs were recalculated for the individual research trial conducted within each job.

DISCUSSION

The value of a good V-blade for efficient and effective site preparation for the mechanical planter is well demonstrated in these trials. The number of trees planted per unit area, the percentage of missed planting spots, and the interrow spacing all attest to this fact.

Stumps

The tractor operators were instructed to avoid stumps where possible and remove them only if absolutely necessary. They were also instructed to swing towards the previously planted row when avoiding stumps so that the interrow spacing would remain tight and not widen. (The increased number of trees per unit area from improved spacing should override any losses from occasionally covering the adjacent row.) The Upsala site had the lowest number of fresh stumps (391/ha) but these were the largest encountered (34.1 cm avg diam.). Their effect is shown in Tables 12 and 13 where they accounted for twice the amount of nonplanted area (5.0%) on this site in comparison with either of the other sites. One of the main reasons for this high figure is that the wider C & H Plow was used on this site, its greater width predisposed it to encounter more stumps.

Greater numbers of slightly smaller stumps on the other sites (788/ha and 1138/ha) tended to have little effect on the planting (2.8% and 2.1% loss) when the Timberland Plow was used. Generally, stumps were not a hindrance to the forward progress of the planting unit.

Slash

Slash 7 cm in diameter and greater occurred in volumes up to 145.8 m^3/ha (Table 2). By themselves these small volumes have little effect on the forward progress of the planting unit. The V-blade swings this material until it passes out of the planter path. However, such material can rip out planted trees in adjacent rows and can be encountered on several passes. At the narrow interrow spacings of 2.44 m and 2.47 m at Vermilion Bay and Foleyet, respectively, 10% and 7.4%, respectively, of the trees in the adjacent rows were affected. The Upsala site had wider interrow spacing (2.82 m) and still 11.8% of the trees in adjacent rows were affected by slash and debris.

Small material, less than 7 cm diameter, if missed by the V-blade, is a relatively minor hindrance to the operation of the planter. It can cause bending or breakage of the nylon tree-holding fingers if encountered during the planting cycle. It can also pull trailing tree seedling roots from the dibble with the result that the tree is loose or improperly planted.

Residuals

Scattered residuals cause no real problem in the operation. It is usually better to leave them standing. The heavy brush encountered only on the Upsala site (13,982 stems/ha over 80% of the area) hid stumps, created more debris to push aside and was generally a cause of wider interrow spacing and lost planting area. A specific figure is not assigned to brush-caused productivity losses, but on the Upsala site brush was an important contributor to a 21.0% loss in plantable sites along the rows and a general decline of 500/ha in the number of trees planted.

Soil

A variety of soils were encountered in the trials, but all were of sufficient depth for machine planting. The clay soil encountered in Vermilion Bay in the spring remained frozen in patches until June. Unfrozen clay, however, was generally easy to plant by machine. Excavations in the heavy clay soil showed that packing was incomplete. Steps were taken to increase packing pressure by using higher operating pressures for penetration and packing. Considerable downtime resulted as the machine was not prepared at that time for such high operating pressures. Wet clay turned soupy in planting and was one of the major causes of unplanted trees (Tables 11, 13).

The sandy loam soil was excellent for planting at Upsala, and at this site difficulties were created by stumps and debris and by mechanical problems related principally to overheating.

Soft sand and the choppy topography combined with limp planting stock to reduce the effectiveness of planting at Foleyet.

Planting Stock

Little reference has been made to the effect of planting stock characteristics on the performance of the planter in terms of planting quantity and quality. Stock should be of a uniform size (Fig. 7) to facilitate efficient handling in the planting machine (Cameron 1975). Stock with undesirable physical attributes in terms of machine planting would include large or heavy stock, i.e., trees larger than those for which the machine was designed, small stock, i.e., trees of narrow root collar diameter which would slip through the tree-holding fingers or limp stock which is not sufficiently firm (woody stem) to support the tree in an upright position once planted. Stiff roots and long roots can be difficult to place in the dibble and can be dragged out prematurely in the planting operation.

Assessment of stock, both seedling and transplant, on one site showed that over 80% of the stock had deformed root systems, J-, L-, or kinked (Clarke and Trayes 1980) as a result of cultural practices in the nursery. Because of this, a large percentage of the stock would require orientation before manual placement in the dibble. In terms of planting productivity and density this is very detrimental (Fig. 8) as consistent and satisfactory planting requires that the roots be contained within the dibble. Root length and shoot length both varied considerably in the planting stock used. More attention to reducing stock variability will be necessary to enhance both production and planting quality.

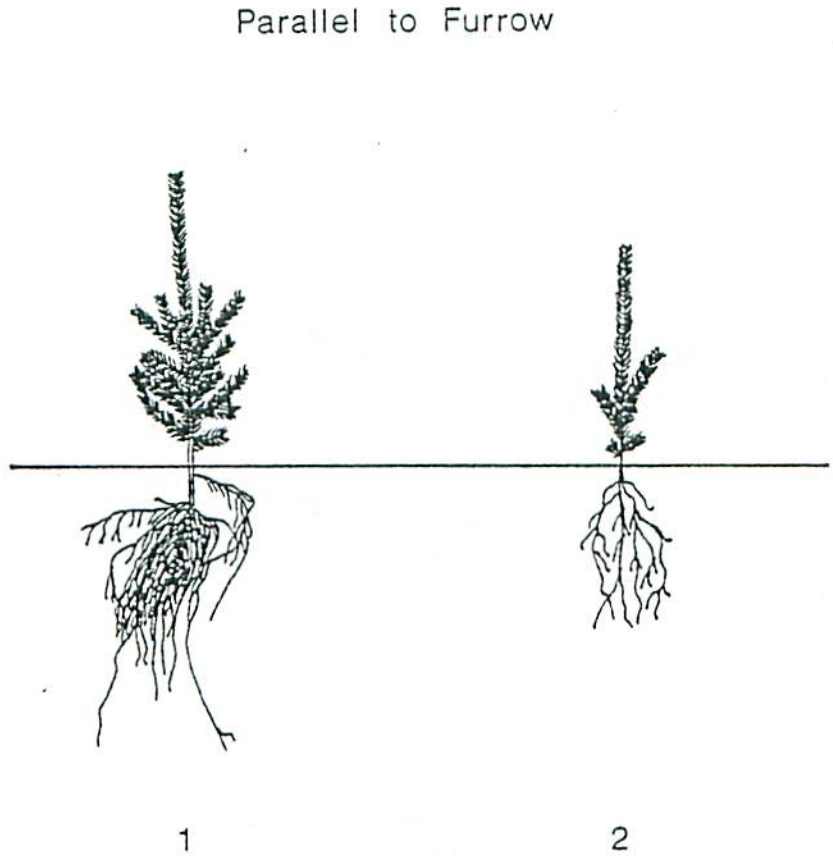


Figure 7. Transplant (1) and seedling (2) stock differ in size and form. Generally speaking, seedling stock is preferred in mechanical planting because of handling ease. Uniformity in size is an asset in efficient handling.

The appearance of the stock to be planted and PMS (plant moisture stress) readings done by Day as part of the aforementioned contract lead us to believe that the stock should have a good chance of surviving (Appendix II, Table A1).

Well balanced (root:shoot) bareroot stock in the order of 15 to 30 cm crown length and 3.5 to 8 mm root collar diameter seems to be the most suitable for machine planting in the planter's present design configuration. For the three main boreal conifers used in these trials (black spruce, white spruce and jack pine), the stock

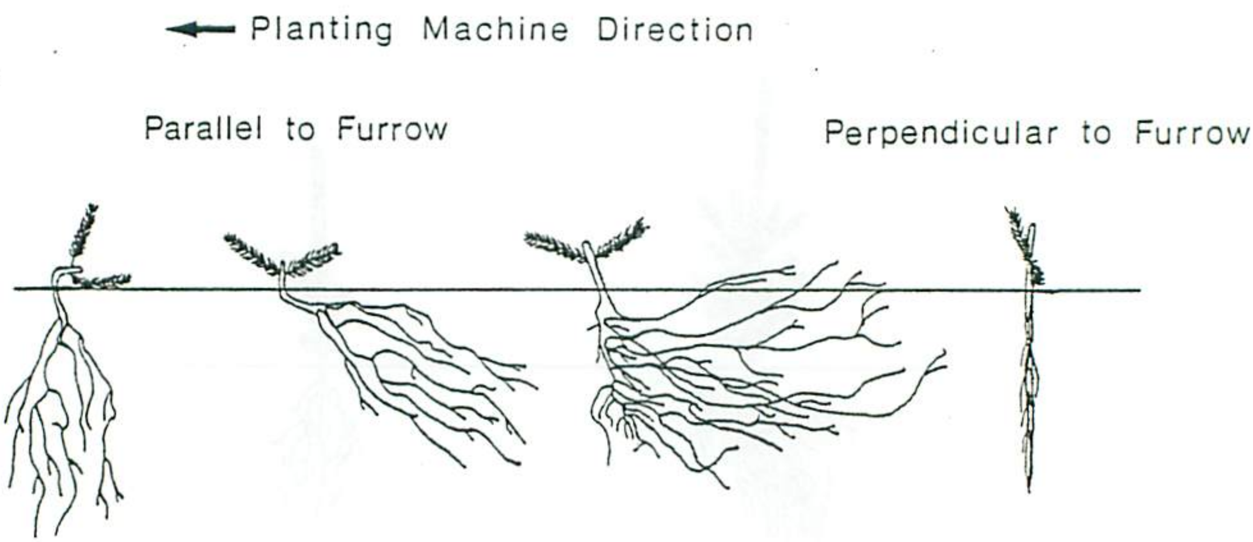


Figure 8. From left to right, a schematic representation of three types of deformed root systems as viewed at right angles to direction of planting: roots inserted perpendicularly in dibble, crown inserted perpendicularly, and the effect of long trailing roots which cannot all be contained within the dibble configuration of the Timberland Planter. Adapted from Clarke and Trayes (1980).

would generally be medium grade (*cf.* Reese and Sadreika 1979) seedling material, i.e., 3 + 0 white spruce and black spruce, 2 + 0 jack pine. In addition it was found that $1\frac{1}{2} + 1\frac{1}{2}$ (2 + 1) transplants of spruces, white and black were suitable as well[5]. If Day's (1980) classification is used, the stock for the above ages should fall within the size range mid-B to mid-D in terms of height, root collar diameter and root area index for efficient operation of this tree planting machine.

Modifications

In chronological order beginning with the Vermilion Bay plant the following modifications were made. The limit switch triggering the packing wheels was replaced with a proximity switch which has no moving parts and will withstand the shocks to which the limit switch had to be subjected. The trigger plate hinge pin was held by two washers and

[5] Smith, Bill. 1979. Timberland Tree Planter, Thunder Bay District September 1979, Ont. Min. Nat. Resour., 7 p. (Internal Report).

cap screws. The rugged service expected of this part was too much for the cap screws and so the washers were welded to eliminate the cap screws and the problem. The planting beam guide developed cracks in a small welded section which has since been redesigned and replaced.

The planting beam cylinder was understrength, and this caused the head of the piston rod to be sheared off. The addition of specially designed larger capacity cylinders relieved this problem but slowed the planting cycle considerably. A further cylinder redesign along with appropriate hydraulic capacity changes returned the planter to its original operating speed. The ejector assembly was completely redesigned to provide simplicity and ease of servicing much superior to those of the original design. Most of the ejector downtime was the result of hydraulic leakages at the fittings or fitting breakages which required a great deal of time to expose and service. Overheating in the hydraulic system tended to cook the leather seals in the cylinders. This led first to the choice of teflon seals and then finally to the adoption of cast steel piston rings which eliminated the internal leakage.

The original hydraulic hose couplings were easily damaged during servicing, and as they were not 'reusable' the supply of custom-made lines was quickly exhausted. The change to another brand necessitated a lengthy wait for parts. No problems were encountered after the changeover.

Overheating became a problem early in the trials because of leakage past hydraulic valves and the high pressures under which the work was originally done.

Later downtime resulted from systematic part by part search for the cause of this leakage and consequent overheating. During this search, which included removal and checking of the pressure relief valve and check valve, airlocks occurred. Slower cycle time resulted in the interim. A complete check in the shop and the over-designing of some components are expected to remove the problem.

The original single plate planter tow hitch had been hastily redesigned after the Vermilion Bay job because of two broken hitch pins, one the result of misuse. In short, the redesign was a step backwards. The original hitch has since been reinstalled and should be completely satisfactory.

In addition to planter modifications, the trials demonstrate the need for a narrow clearing width for close interrow spacing and hence more trees per unit area (Tables 12 and 14). Scalpers are necessary only on brushy sites, sites where a heavy root mat must be removed, and sites where it is otherwise desirable to bare the mineral soil for planting.

Further modifications for housekeeping purposes and ease of servicing are being added to production model planters by Timberland Equipment Ltd.

Safety

The streamlined front end, low centre of gravity, high strength metal covering and generous use of lexan all contribute to a safe and damage-resistant planting unit. It has a secure and comfortable seat set at a convenient working height and is equipped with R.O.P.S. canopy. A horn is standard equipment and a necessity for operator safety and communication. The emergency recall button will stop and recall the planting beam and packing wheels at any point within the planting cycle. It is a valuable and necessary item for both safety and machine protection. The diesel engine operates at a governed maximum speed and there is a fuel shutoff valve for safety as well as a low hydraulic oil automatic shutoff switch to protect the hydraulic components.

A bulldozer drawbar hitch which is free to rotate on the roll axis is completely unsuitable for use with towed planting machinery, because with such an arrangement the planter can upset in rough conditions, even though it may have built-in restraints. This type of hitch was used on the Upsala and Foleyet jobs. Some time was spent welding rolling restraints on the hitches to immobilize them but they required constant inspection and occasional mending throughout the trials. For safety's sake, a fixed drawbar hitch is most suitable.

In addition, the V-blade which removes debris from the planting path can be considered an important safety feature for mechanical tree planting in boreal forest conditions.

Cost

The costs for machine planting, as revised, exceeded reported District costs for handplanting and site preparation. There are some mitigating factors to consider, however. This was an accommodation-and-meals provided operation rather than a commuter operation, the general type of operation carried out by OMNR. All costs associated with moving across Ontario, wages, room and board are included. Individual district jobs would pay only for 'on site' work and some associated commuter travel time.

The nature of this operation required the retention of extra manpower on site for contingencies.

In this contract situation, all costs had to be "up front" including all supervision, preplanning, overhead, miscellaneous costs and profit, and these costs had to be reported so that full payment could be received according to the contract agreement.

The costs shown are reasonable in light of the circumstances involved.

The variables of utilization, availability, number of trees/hr, vehicle rental, area, tractor rental, wages, etc., can be changed to produce a wide range of costs, some acceptable, some unrealistic.

Table 17 shows a steady decline in costs as the project progressed. The planting machines with the latest improvements, on a district commuter job, should be comparable to alternative site preparation and handplanting treatments.

SUMMARY AND CONCLUSIONS

Two Timberland Planters were cooperatively tested by OMNR and GLFRC to assess their performance. The Timberland Planter is an intermittent dibble, bare-root, mechanical tree planter in which the planting mechanism is carried clear of the ground (free of obstacles) when not planting a tree. It is a trailed unit which has a self-contained power source for its hydraulic and electrical systems. It is manually fed by a planter operator seated in the planter. The planter has no site clearing ability of its own and therefore requires a bulldozer in the 60 to 140 hp class equipped with a V-blade and scalping foot to prepare the site.

This report covers the results obtained from operational plantings carried out in the spring and summer of 1979 in three boreal forest cutover sites across northern Ontario. D7F Caterpillar bulldozers were used and were equipped with either the Timberland Plow or the C & H Plow. Site conditions such as stumps, slash, residuals, soil, slope, and ground roughness were assessed to determine their effect on planting rate and quality so as to gain an understanding of the Timberland Planter's capability, reliability, and safety. The machine was modified in the field as work progressed and between trials where changes were required in a general upgrading of the machine.

With the exception of the time spent refueling and waiting for hand planters to catch up, operating practice was good. Machine availability and utilization improved dramatically over the season as flaws were detected and corrected. The final job had 94% availability and 73% utilization. Future users should expect high availability; utilization depends on the user.

Interrow spacing is controlled by the V-blade and tractor operator and is governed by site conditions. The Timberland Plow consistently outproduced the C & H Plow in terms of planting attempts per ha and satisfactory plantings per ha. Site preparation that results in either shallow furrow or removal of debris only, with the soil left intact, produces the most successful machine planting.

Trees per productive machine hour averaged 887 in Foleyet for the five-day trial period. A minimum of 800 per hour should be achieved in future plantings, while the indications are that a rate of 900 per hour is attainable over long periods.

Independent planting assessment rated machine planting attempts satisfactory 65-75% of the time with an additional 10% being hand corrected. Our assessments indicate that there is room for improvement in this area. The machine modifications, plus the use of more suitable planting stock, should improve this performance.

A field crew familiar with the planter operation and able to follow operating instructions is essential. The Timberland Planter, like any other machine, must be serviced regularly. For maximum efficiency the planting operation should be planned to capitalize on long runs. Regular restocking should be provided for and a two-man planter crew should be used, the one relieving the other at regular intervals. Hand correction of machine misplants should be sufficient but some additional filling-in may be a reasonable and desirable supplement to an efficient machine planting job. Provided that the planting microsite is properly prepared, the actual planting is a fairly simple matter.

While the cost of this operational planting was high, the circumstances, which involved the legitimate expenses of maintaining a larger crew, moving across Ontario, and planting some artificially small chances as well as the provision of room and board to the crew, tend to put that cost in a poor light.

The Timberland Planter has shown itself to be a safe machine for use in boreal forest cutover conditions. With the modifications indicated, the Timberland Planter is a rugged machine capable of planting on a wide range of sites.

LITERATURE CITED

ANON. 1969. Terrain classification for Swedish forestry. Skogsarbeten, Drottninggstan 97. 113 60 Stockholm, Sweden. Report No. 9. 10 p. + appendices.

ANON. 1979. Operational trial of the Timberland tree planter 1979. KBM Forestry Consultants Inc., Thunder Bay, Ontario. 29 p. + appendices, unpublished.

BERARD, J.A., DIBBLEE, D.H.W. and HORNCASTLE, D.C. n.d. Standard definitions for machine availability and utilization. Can. Pulp Pap. Assoc., Woodl. Sec. Index No. 2428 (B-1). 4 p.

CAMERON, D. A. 1975. A guide to planting machine operation in the boreal forest of Ontario. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Report O-X-234. 23 p.

CAMERON, D. A. 1978. The CFS V-blade. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Report O-X-278. 10 p.

CLARKE, F. R. 1977. Evaluation of the C and H plough. Ont. Min. Nat. Resour., Div. For., North Central Region. 21 p + appendices.

CLARKE, F. R. and TRAYES, A. E. 1980. Attributes of bare root nursery stock for mechanical planting. Lakehead Univ., Sch. For. 13 p. (mimeo).

DAY, R. J. 1980. A guide to size class standards for northern Ontario nursery stock (operational edition). Lakehead Univ., Sch. For. Silv. Rep. 1980-1. 30 p.

HILLS, G. A. 1955. Field methods for investigating site. Ont. Dep. Lands For., Site Res. Manual No. 4. 120 p.

REESE, K. H. and SADREIKA, V. 1979. Description of bare root shipping stock and cull stock. Ont. Min. Nat. Resour., Toronto, Ont. 39 p.

RILEY, L. F. 1975. Operational testing of planting machines in the boreal forest of Ontario. I. Reynolds-Lowther heavy duty crank axle planter. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Report O-X-219. 37 p. + appendices.

ROWE, J. S. 1972. Forest regions of Canada. Dep. Environ., Can. For. Serv., Ottawa, Ont. Publ. No. 1300. 172 p.

SCOTT, J. D. 1975. Recent developments in mechanized planting and the future for Ontario. p. 70-85 *in* Mechanization of silviculture in northern Ontario. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Symp. Proc. O-P-3.

SUTTON, R. F. 1967. Influence of planting depth on early growth of conifers. Commonw. For. Rev. 46(4), No. 130. p. 282-295.

APPENDICES

APPENDIX I

Definition of Terms

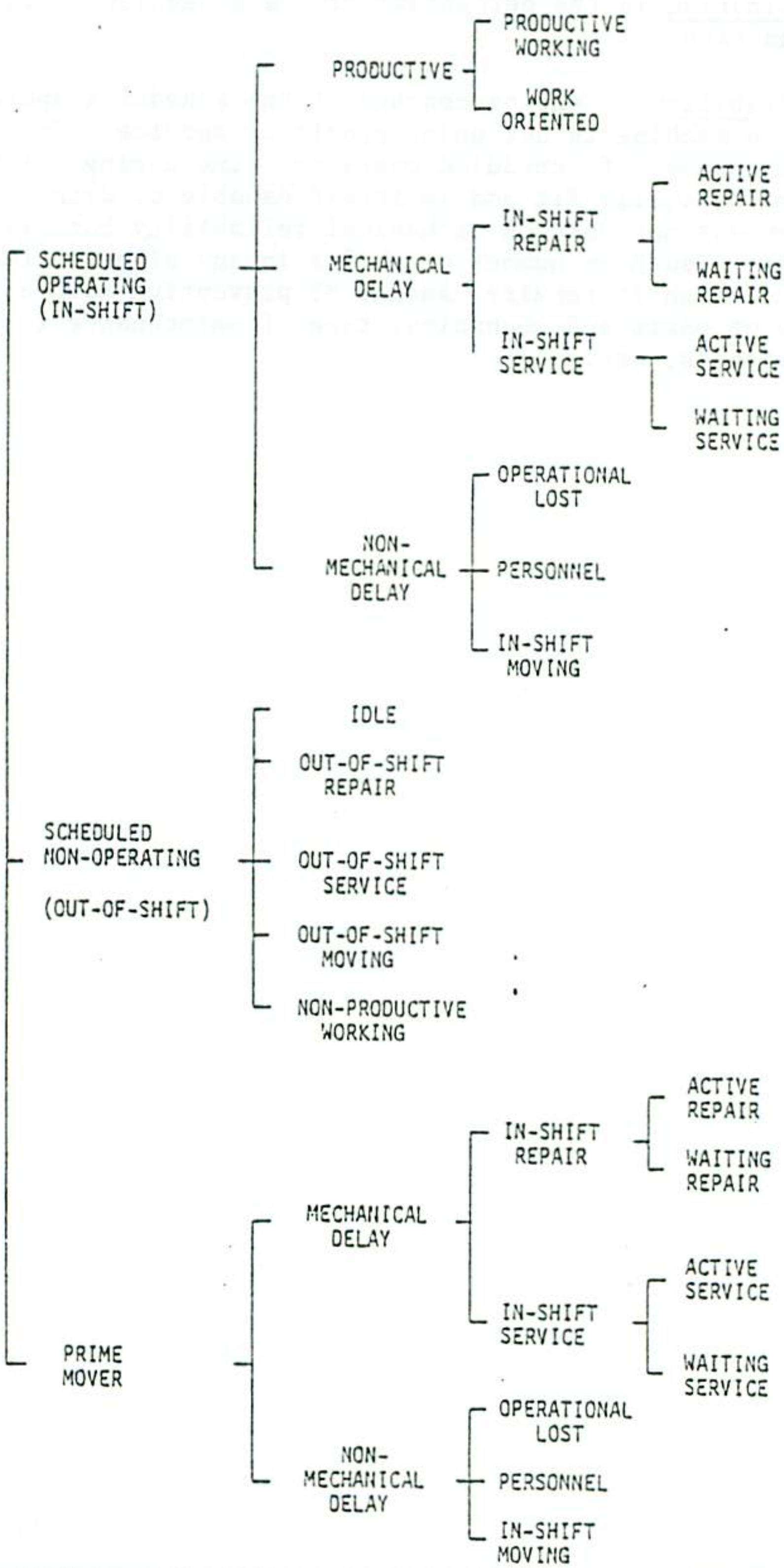
Utilization is the percentage of the scheduled operating time that is productive.

Availability is the percentage of the scheduled operating time during which a machine is not under repair or service. In other words, it is the percentage of scheduled operating time during which the machine is mechanically fit and is itself capable of doing productive work. It depends not only on mechanical reliability but also on external factors such as number of shifts in any elapsed time period, extent of out-of-shift repairs, amount of preventive maintenance, availability of parts and mechanics, type of maintenance facility, skill of mechanics, etc.

(continued)

APPENDIX I (concluded)

ELEMENTS OF MACHINE TIME[a]



[a] Adapted from Bérard et al. (n.d.). Refer to Bérard for further information on time elements.

APPENDIX II

Table A1. Planting stock morphological quality[a]

	Physical appearance	Ht[b]	RCD[b]
Vermilion Bay 12 days of sampling spruce, white and black	top dormant to buds swelling, roots swollen, healthy appearance	Low A to high D normal	High A to Low D smaller than normal
Upsala 13 days of sampling spruce, white and black	top dormant to buds bursting or shoot elongation, no root activity to swollen or short elongation, healthy appearance	Mid-A to low C taller than normal	High A to high C larger than normal
Foleyet 7 days of sampling jack pine	top dormant to buds bursting or shoot elongation, no root activity to swollen or short elongation, healthy appearance	High B to low C normal	High D to mid-E smaller than normal

[a] Results courtesy of R.J. Day, Professor, School of Forestry, Lakehead University from assessments conducted under OMNR contract.

[b] Day (1980) classifies nursery stock as A, B, C, D, or E. C represents normal, A is higher than normal and E is lower than normal for height (Ht) and root collar diameter (RCD).